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Dynamics of Sandwaves under Combined Wave - Current Forcing and Mine Burial Processes, and Instrumentation for Measuring Nearshore Morphologic Change and Hydrodynamic Forcing

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LONG-TERM GOALS

Our long terms goals are to understand sediment transport processes, the relevant physical forcing processes and the resulting morphologic evolution of river mouths and tidal inlets and shoals. Specific goals include understanding bedform characteristics (ripple to sandwave and sandbar scale) in relation to wave- and current-forced mean and turbulent flow.

OBJECTIVES

1. Measure the currents, hydrodynamic boundary layer processes, sediment-transport processes and bedform evolution in energetic ebb-tidal shoal environments, where nonlinear interactions between waves and tidal currents are critically important to the sediment transport and the morphological response to changing forcing conditions.
2. Determine the mechanism responsible for the burial of mine-like objects in regions of active bedforms.
3. Develop instrumentation to make essential measurements for the above objectives. This includes autonomous and manned survey vessels with a carrier phase GPS and Doppler profilers for resolution of near bed turbulence and flow.

APPROACH

In order to measure the processes responsible for inlet morphologic change we conducted repeat bathymetric and hydrographic surveys along with in-situ time series measurements of water velocity (waves and currents), sediment transport (both suspended load and bedload via bedforms migration) and bed elevation. In 2012, we focused on measurements in New River Inlet, NC as part of the first phase of the rivers and inlets (RIVET) DRI. Our approach to this project consisted of combined spatial shipboard and AUV surveys with in-situ measurements from seafloor mounted frames (quadpods). The spatial surveys were conducted with a small boat with an ADCP, and motorized kayak with sidescan, echosounder and post-processing kinetic (PPK) GPS system and a REMUS-100 AUV with an ADCP, sidescan and PPK-GPS system. Grab samples and CTDs were also collected from the small

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boat. The goal of the combination of these survey vessels was to document the spatial variability of bedform geometry, bed grain size, and flow velocity on time scales that resolved tidal variability. The vessel/AUV survey data provide a larger scale context with which to interpret the high-resolution quad-pod measurements.

The in-situ quadpod measurements were optimized to measure sediment transport processes and forcing hydrodynamics. A particular focus was the temporal evolution of the bedform geometry and migration combined with the wave and current hydrodynamic forcing for these changes. The quadpod measurements also included profiles of turbulence, as turbulence is both modulated by the bedforms and forces the sediment transport processes controlling bedform evolution. Both bedload suspended load sediment transport processes were resolved, with bedform migration serving as a proxy for bedload and acoustic backscatter profiles were used for suspended load.

Once formulations for sediment transport processes and bedform evolution have been developed, these formulations can be used in models to understand the relative roles of the processes in morphodynamic evolution of the inlet system. Models can also be tested using both the quadpod and the spatial survey velocity measurements.

In terms of mine burial, our approach is to examine the coupled bedform mine system as burial and scour processes are often closely coupled to bedform dynamics.

WORK COMPLETED

The observations at New River Inlet consist of time-series measurements from quad-pods at two locations from May 2 to 24, high-resolution bathymetric/bedform/velocity surveys, and large-scale vessel/AUV measurements of velocity (Table 1). Repeated side-scan surveys across the inlet (Figure 1) indicate significant spatial gradients in bedform amplitude, wavelength, orientation and migration rate that depend on the local intensity of flow, wave orbital amplitude, and the overall flow geometry (Figure 2). Fifteen grab samples were collected along a cross-inlet transect aligned with the quad-pods to examine the relation between the spatially variable flow and bedforms. Fieldwork completed for the mine burial project has been documented in previous annual reports.

Instrument Development

The REMUS-100 with the PPK-GPS surface piercing antenna prototype was completed and tested for stability in variety of conditions. The system proved stable in mild conditions, and could keep the antenna from submerging for extended periods in moderate wave conditions. In highly energetic wave conditions combined with strong currents, heave and roll stability limited the performance of the GPS antenna. The same PPK-GPS that was used on the REMUS-100 was used in the motorized kayak shipboard bathymetry and sidescan surveys to document the spatial variability of the bedform field. This system produced excellent data (Figure 1) as stability was not an issue, and the operator could adapt the survey plan to changing conditions such the presence of absence of breaking waves. Upgrades to our pulse coherent Doppler system were also finalized and the new bistatic configuration was used in both the OASIS measurements at MVCO and in New River Inlet. This system produced excellent data documenting the turbulent flow over the bedforms (Figure 3). This instrumentation will play a prominent role in upcoming work focused on mine burial.

Table 1. Instruments, platforms and data acquired

Instrument/platform	Quantity Measured	Sampling Rate, Duty Cycle
QUADPODS:		
Nortek ADVs, 2 per pod @ z = 75cm	Point measurement of turbulent and mean u,v and w velocity components	16 Hz continuous
WHOI Pulse Coherent Doppler Profiler 1 per pod, 1 cm resolution profiles from 1.2 m to seafloor	1 cm resolution profiles of from 1.2 m to seafloor of turbulent and mean u,v and w velocity components	10 min per hour 10 Hz
Rotary Sidescan Sonar, 1 per pod	Short (5m) Range, high resolution sidescan imagery of bedform in vicinity of quadpod	30 min
	Long (20 m) Range, medium resolution sidescan imagery of bedform in vicinity of quadpod	8 Scans / hr
Rotary 2-axis pencil beam sonar	Short (3m) Range, high resolution topographic maps bedform in vicinity of quadpod	1 scan/ hr
Acoustic Backscatter Profiles (ABS)	1.0, 2.5 and 5.0 MHz 1 cm resolution profiles of from 1.2 m to seafloor of acoustic backscatter to quantify suspended sand concentration	20 min per hour 2Hz
SURVEY REMUS AUV: Sidescan and ADCP surveys	Bedforms geometry and Flow structure	Variable
SHIPBOARD SURVEY: ADCP surveys in select portions of inlet with focus on quadpod transect, and grab samples	Flow structure and grain size	Tidally Resolving, Spring and Neap Surveys
CATYAK (Catamaran Kayak) SURVEY: Sidescan, Echosounder and PPK phase resolving GPS surveys in select portions of inlet with focus on quadpod transect.	Bedform geometry and bedform resolving bathymetry	Tidally Resolving, Spring and Neap Surveys

RESULTS

The rotary sidescan sonar and 2-axis rotary pencil beam sonar measurements from the quad-pods as well as the bathymetric/bedform surveys indicate that the large-scale bedform geometry changes significantly through the observation period, and variations of small-scale bedforms are observed on timescales of hours. For example, the rotary sidescan images in Figure 4 shows sheet-flow conditions over large dunes (4 m wavelength, 40 cm height) during maximum ebb, but 3 hours later the entire field of dunes is covered with large ripples (50 cm wavelength). The adjustment timescale of the large dunes appears to be about 1-2 tidal cycles, and their structure and evolution appear to depend both on the tidal current amplitude and wave conditions (movies are available at http://vimeo.com/ptraykovski). The conditions at the end of the deployment with weaker tidal flows (Figure 5) indicate the absence of large-scale bedforms (compare to Figure 4 at the same scale), apparently due to the reduction of tidal forcing.

An initial attempt at image to image cross correlations from the pod in the SW channel reveal migration rates of the large bedforms at rates up to $U_{bedform}$ = 2 m/hr during strong spring tide ebb flows (Figure 6). The flows and migration rates during flood and both phases of neap tide are much smaller. The migration rates appear to scale as U^3. The ripple migration data was used to estimate bedload sediment transport rates as $Q_{bedform} = (1-\epsilon)0.5\ \eta U_{bedform}$, where η is the measured ripple height, and the scaling factor 0.5 assumes an approximately zero skewness ripple geometry, and the porosity was assumed to be 0.5 also. The bedload transport can be compared to predicted bedload transport calculated using the semi-empirical Meyer-Peter Muller (MPM) formula (Figure 7). While this formula is well established for unidirectional flows, it has not been tested with tidally reversing bedforms that are often found in inlets. To fit the cumulative bedload transport rate the MPM formula was used with a quadratic stress estimate with the coefficient of drag adjusted to 0.0014. This is a reasonable C_d that is roughly consistent or slightly lower than other studies on tidal flows. The low value might be a result of the partitioning between form drag and skin friction, in which the skin friction is used in the MPM formulas. We have not yet compared it other estimates of skin friction or form drag stress in the SW channel of New River Inlet. This result has important implications for bedload transport modeling as it suggests that traditional approaches should be successful to first order. The data does show an approximately factor of 2 variability about the predictions, with flood tide bedform migration flux under predicted, and neap tide migration flux over predicted. Further analysis will examine this.

The pulse-coherent Doppler velocity profiler (PC-ADP) provides turbulent velocity data at 1-cm resolution across the bottom boundary layer, allowing the influence of the bedforms on the boundary layer turbulence to be examined and quantified. One of the first tasks we will undertake is to estimate stress values from the PC-ADP to compare to the MPM formula above. As bedforms migrate past the insonification column of the PC-ADP, the structure of the induced turbulent wake can be documented. Figure 3 provides an example of a segment of horizontal and vertical velocity data just downstream of a large bedform that clearly indicates the turbulent wake structure. Bursts of low-momentum fluid (are associated with positive values of vertical velocity and extend 20-30 cm vertically, roughly the scale of the dunes themselves. This wake structure has leading-order consequences for both the effective turbulent stress and the sediment transport.

IMPACT/APPLICATIONS

While analysis to this data set has just begun an increased understanding of sediment transport processes in tidal inlets and bedform evolution, will allow better prediction of the morphodynamic response of the system to variations in forcing parameters. Quantifying the relations between bedform geometry and frictional drag will also aid in an increased ability to model the flow field in environments such as this.

RELATED PROJECTS

Three grant numbers are included in this report as N00014-10-10768 (Instrumentation for Measuring Nearshore Morphologic Change and Hydrodynamic Forcing) is a DURIP to develop equipment for the scienece projects: N00014-10-10376 (Multi-Scale (cm to km) Hydrodynamic and Morphologic Interactions in Tidal Inlets) and N00014-11-10291 (Dynamics of Sandwaves with Combined Wave - Current Forcing and Mine Burial Processes), which are highly related.

This project is also closely related to several other proposed ONR efforts including an OASIS project with John Trowbridge to measure wave boundary layer stresses in support of optical measurements of particle dynamics (Environmental Optics), and integrating the pcADPs on Geyer's MAST (Physical Oceanography). The DURIP funding was also used to develop equipment for those projects.

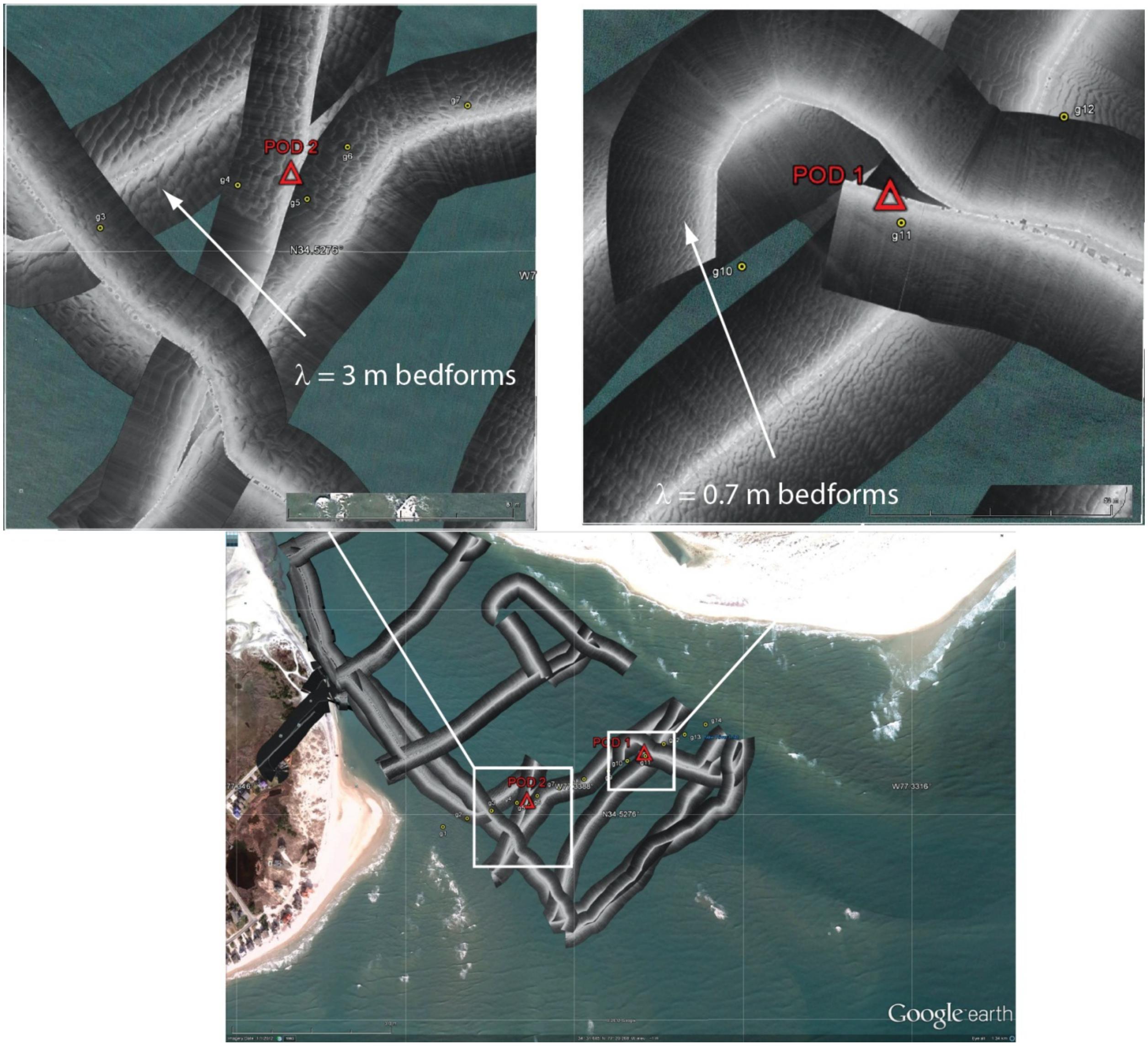

Figure 1. Sidescan sonar survey of New River Inlet showing the location of our two quadpods in the NE and SW channels. The surveys consistently show larger bedforms near Pod 2 and smaller bedforms near Pod 1.

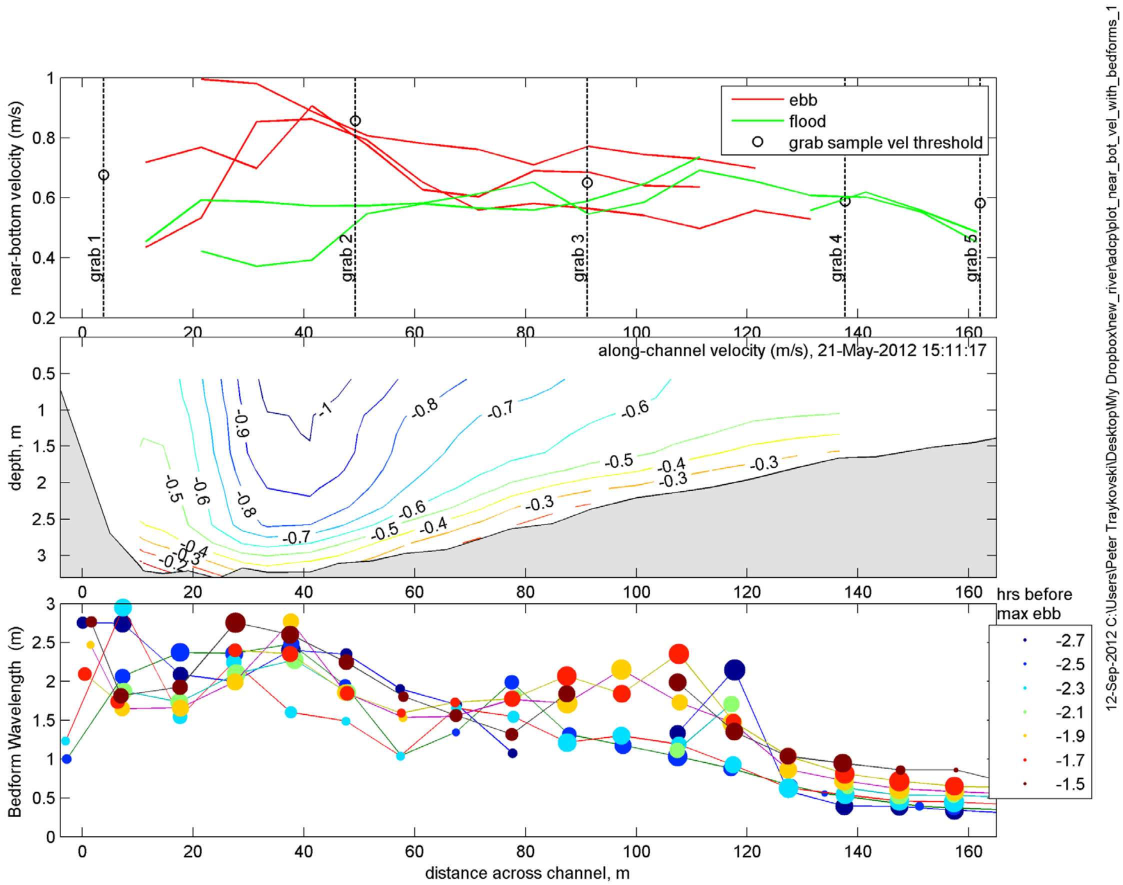

Figure 2. Along channel flow 2 hours after max ebb, and bedform wavelength leading up to max ebb.

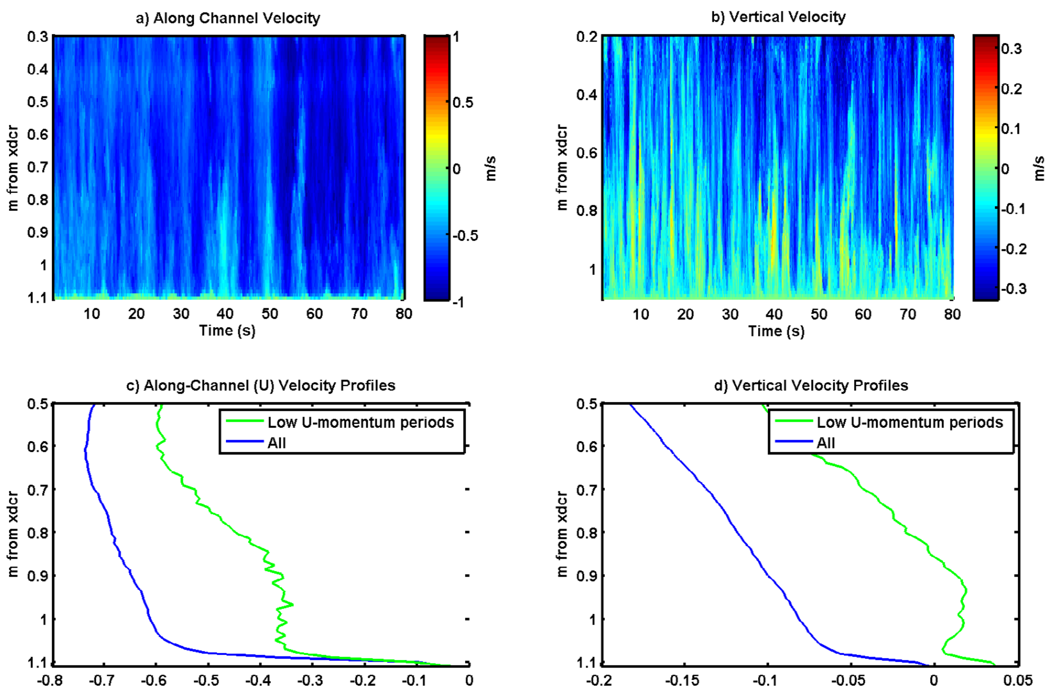

Figure 3. A pulse-coherent Doppler velocity profile close to max ebb flow with a crest of a dune (Figure 2 left panel) just upstream of the profiler. The color plots of along channel velocity (a) and vertical velocity (b) show periods reduced along channel flow associated with upward bursts. Conditionally averaging the periods with reduced along channel flow (c, green line) shows a clear inflection point in the velocity profile indicative of flow separation over the dune crest. The same conditional sampling also shows upward vertical velocities (d). Mean vertical velocities are downward due to flow distortion around the upper part of the frame.

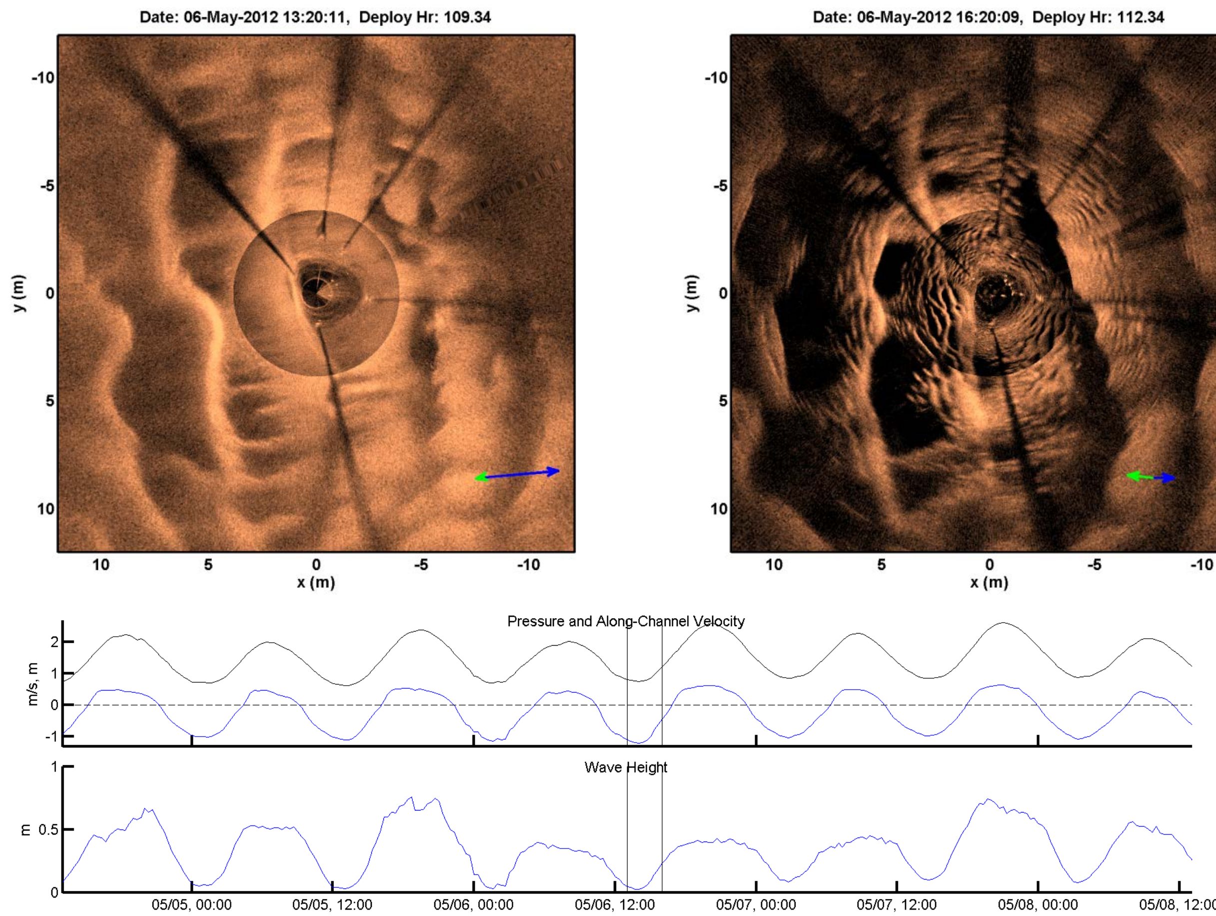

Figure 4. Rotary sidescan images taken during Spring tides at the beginning of the deployment near max ebb flow (~ 1.0 m/s, left) and during slackening ebb flow three hours later (~ 30 cm/s, right). During max ebb flow, large dunes with wavelengths of 4 m are present with sheet flow sediment transport. A crest of dune is just upstream of the tripod as seen by the shadows of the legs. As the flow slackens, smaller ripples with wavelength of 50 cm appear.

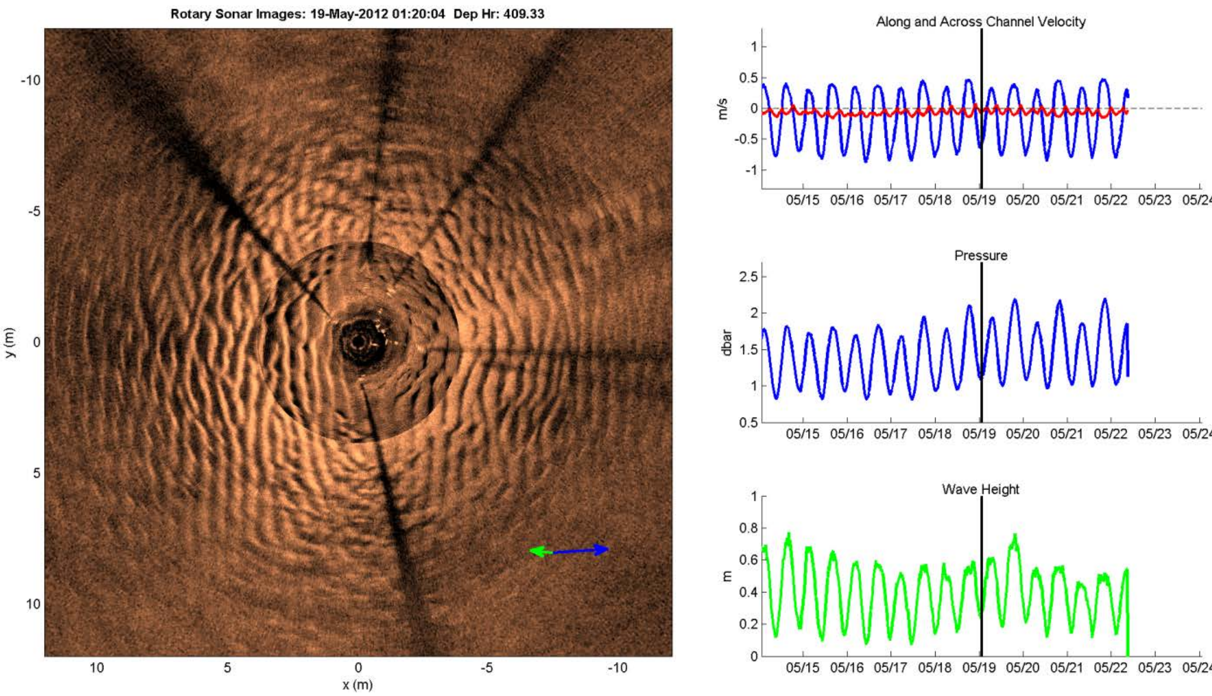

Figure 5. During neap tides towards the end of the deployment large dunes are not formed during max ebb flow, instead medium size (wavelength of up to 1 m) dunes are present.

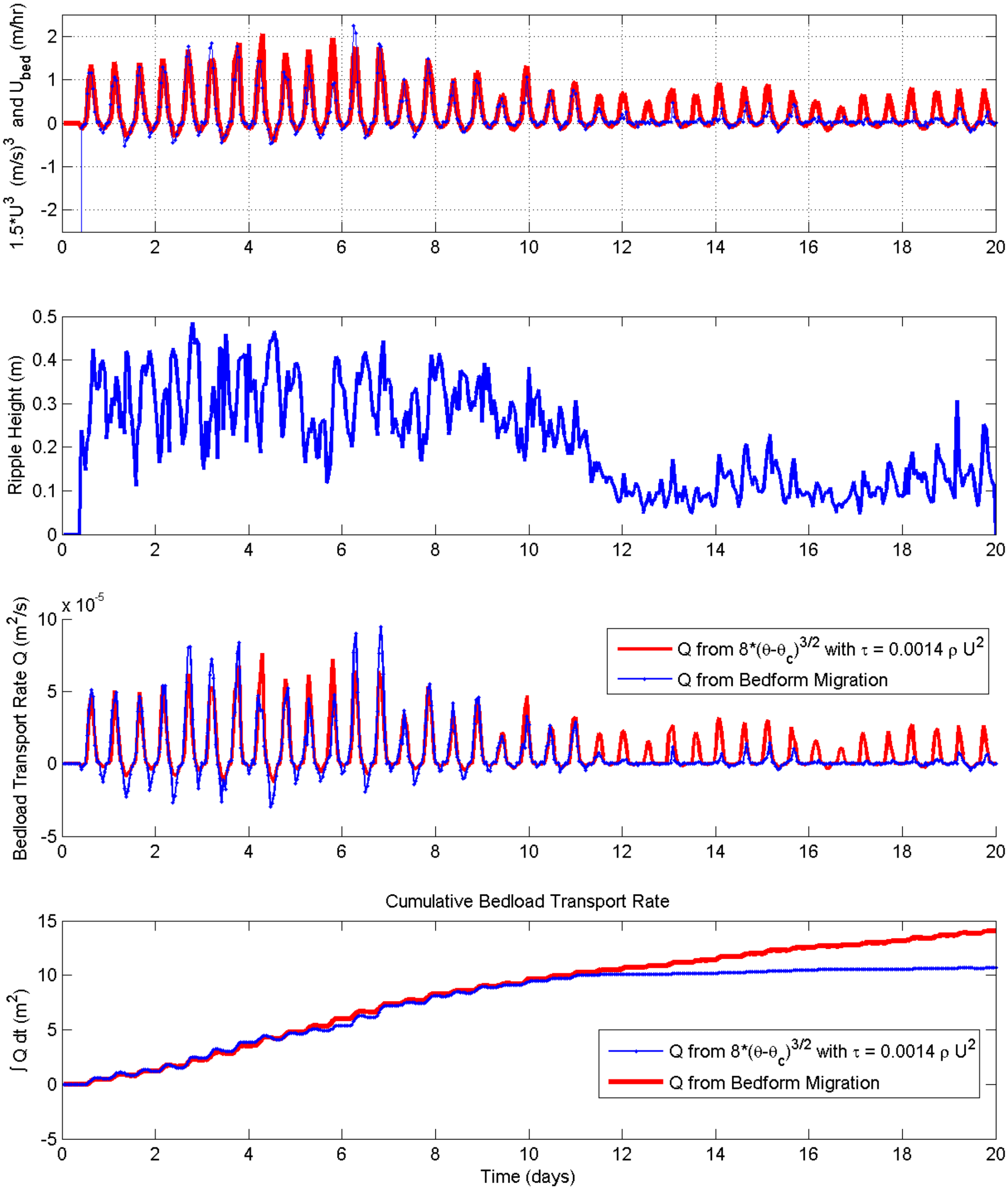

Figure 6. Bedform Migration and Along Channel flow at the SW quadpod. A) Bedform migration and U^3. B) Ripple Height. C) Meyer-Peter Muller bedload predicted and measured ripple migration bedload transport rate. D) Cumulative transport rates

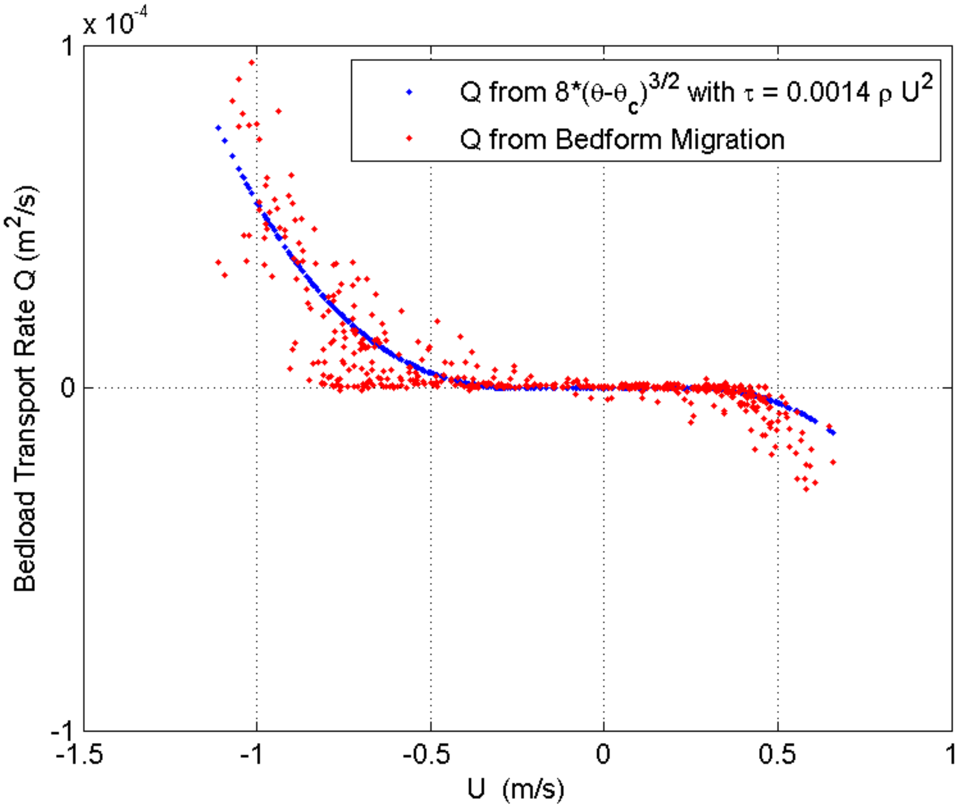

Figure 7. Meyer-Peter Muller bedload predicted and measured ripple migration bedload transport rate.